RESPONSE OF APPLE AND WINTER PEAR FRUIT QUALITY TO IRRADIATION AS A QUARANTINE TREATMENT[1]

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ABSTRACT

Irradiation at doses between 0.30 and 0.90 kGy reduced apple firmness. Doses of <0.30 kGy had no effect on apple firmness. Firmness lost due to irradiation was cultivar dependent. Titratable acidity (TA) of 'Gala' apples was reduced at irradiation doses of 0.60 kGy and above. No loss of TA due to the irradiation dose was evident, for 'Fuji' or 'Granny Smith' apples. Irradiation did not influence the external color of apples, but change in the internal color of 'Gala' and 'Granny Smith' apples due to irradiation exposure was present. 'Bosc' pears lost firmness due to irradiation, and the firmness loss was dose dependent. Both, 'Anjou' and 'Bosc' ripened normally after irradiation exposure. There was an increase in scald for 'Anjou' that was dose dependent. Disease incidence of 'Fuji' and 'Granny Smith' apples caused by P. expansum *was reduced from about 80% of wounds with lesions to 30% after irradiation exposure. Irradiation had no effect on number of lesions caused by either* B. cinerea *or* M. piriformis. *No effect was observed on decay of 'Anjou' pear fruit naturally infected with* P. expansum *and* B. cinerea. *However, a reduction in decay was observed in naturally infected 'Bosc' pear fruits treated with 0.90 kGy.*

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INTRODUCTION

Export of agricultural commodities to foreign markets is a major interest of the United States. Fumigation of fruit products with methyl bromide (MeBr) to meet quarantine requirements imposed by foreign countries for insect pest control has met with varying degrees of success, due primarily to injury to the host fruit. At the present time, regardless of the problems associated with fumigants, MeBr is the only treatment accepted by a number of countries that constitute important markets for fruits and vegetables. The future of MeBr as a quarantine treatment is in doubt. In the year 2001, MeBr will be banned as a fumigant in the United States (Stephens 1996). To continue to export agricultural commodities, acceptable alternatives to MeBr must be developed.

Treatment of fresh produce with radiation may be a viable alternative for MeBr. Research has been conducted on irradiation of fruits and vegetables for disinfestation of both insects and decay causing microbes. Loss of quality in fresh produce after irradiation has been reported (Maxie *et al.* 1971). However, sweet cherries (Drake *et al.* 1994; Drake and Neven 1997; Eakin *et al.* 1985; Eaton, 1970; Kader 1986), blueberries (Miller *et al.* 1994), and 'Delicious' apples (Olsen *et al.* 1989) treated with up to 1.0 kGy suffered little or no quality loss. Currently, the FDA allows 1.0 kGy or less on fruits and vegetables (Kader 1986). Eakin (1985) reported that codling moth (*Cydia pomonella L.*) control can be achieved with an dose of 0.25 kGy.

Little information is available concerning the response of different apple cultivars to radiation and none is available on winter pears. This study was initiated to determine the fruit quality response of new apple cultivars ('Fuji', 'Gala' and 'Granny Smith'), and winter pears ('Anjou' and 'Bosc') to irradiation at dosages sufficient to meet quarantine requirements for insect disinfestation.

MATERIALS AND METHODS

Radiation treatments were conducted at Battelle-Pacific Northwest Laboratory, Richland, WA using a gamma beam 650 source containing cobalt-60. Distance of the boxed fruit from the source was adjusted to provide a dose rate of 8.32 Gy/min and varying exposure time for doses of 0, 0.15, 0.30, 0.60 and 0.90 kGy. Dose was measured using a commercially available small volume ionization chamber made from air equivalent plastic. Apple and pear fruit used as controls were also transported and held under similar temperature and conditions as irradiated fruit.

Apple Quality Evaluation

Commercially packed 'Fuji' and 'Granny Smith' apples, size 88, from three grower lots were obtained from Orondo, WA after 90 days of controlled atmosphere storage (1% to 2% O_2, 1% CO_2 at 1C). Packed 'Gala' apples, size 100, also from three grower lots, were obtained from Wenatchee, WA after 45 days of cold storage (1C). Apples were held one to two days at 10C and transported to the irradiator. After treatment, the fruit was transported to Wenatchee, WA and placed in cold storage at 1C. Fruit quality was assessed after 30 or 60 days in cold storage and ripening after 0 or 7 days at 20C.

Pear Quality Evaluation

Three groups of packed, size 100 (220 g) US No. 1 'Anjou' and 'Bosc' pears were obtained from three Wenatchee, WA area packinghouses in 1995 and 1996. In 1995, fruit had been stored for 45 days in cold storage at 1C, whereas in 1996, fruit were obtained within one week of harvest. At packing, pears were coated with a food-grade shellac-based wax. Pears were held one to two days at 1C and transported to the irradiation facility. After treatment, pears were taken to the USDA, ARS-TFRL in Wenatchee, WA and placed in cold storage. Fruit quality was evaluated 30, 90, and 120 days after treatment and ripening.

Fruit quality evaluations were made on each of 20 apples or pears for all combinations of radiation treatment, storage and replication. Ten fruit were evaluated immediately after removal from storage and the other 10 were ripened for 7 days at 20C before evaluation. Quality factors evaluated were external and internal color, firmness, soluble solids content (SSC), titratable acidity (TA), visual disorders and decay.

External color was determined with a color meter (The Color Machine, Pacific Scientific, Silver Springs, MD) using the Hunter L*, a*, b* system and calculated hue (Hunter and Harold 1987). Two evaluations were made on each fruit for external color and one evaluation was made for internal color. Firmness was determined at two locations per fruit with a texture analyzer (TA-XT2, Texture Technologies, Scarsdale, NY) equipped with a 11.1 mm probe for apples and a 7.7 mm for pears, and values were reported in Newtons (N). Soluble solids content (SSC) and titratable acidity (TA) were determined from an aliquot of expressed juice of a longitudinal slice from each of 10 fruit. An Abbe type refractometer with a sucrose scale calibrated at 20C was used to determine SSC. TA was measured with a titrator (TTT 85, Radiometer, Copenhagen, Sweden). Acids were titrated to pH 8.2 with 0.1 N NaOH and expressed as percent malic acid. Physiological defects and disease were assessed visually by two individuals familiar with apple and pear storage problems and disease. A triangular difference, for flavor, between the control

'Anjou' pears and those treated with 0.90 kGy of irradiation was conducted according to the procedures of Larmond (1977). Analysis of variance was determined by MSTAT (1988) with irradiation treatment as the main plots with storage and ripening as the subplots. Grower lots (3) and years were combined for the error term. Based on significant F-tests, means were separated using Tukey's HSDT ($P \geq 0.05$).

Apple Disease Control

To determine if irradiation affected decay incidence, 'Fuji' and 'Granny Smith' fruit from each of the three grower lots were selected about 12 h before irradiation and fruit surface was disinfested with 150 ppm chlorine for 5 min. Apples were placed on new fruit trays and then wounded to simulate stem punctures (5 mm diam x 3 mm deep, 2 wounds/fruit). Wounds in each of 3, 6-fruit replicates were inoculated with aqueous spore suspensions (50μL/wound) of either *Penicillium expansum* Link (2000 conidia/mL), *Botrytis cinerea* Pers.:Fr. (1000 conidia/mL), or *Mucor piriformis* E. Fisch. (500 conidia/mL), as well as sterile water controls. Trays of inoculated fruit were placed in poly-bag lined boxes immediately after inoculation. Disease incidence was assessed 60 days after irradiation. Disease incidence data were transformed to arcsine square root values and analyzed separately for infections caused by each pathogen with two-way ANOVA. Where significant differences were indicated, means were separated with Tukey's HSDT ($P \geq 0.05$).

Pear Disease Control

Commercially packed 'Anjou' pear fruit were obtained from a packinghouse in the Wenatchee, WA area. Fruits had been repacked, primarily because of surface marking (cause unknown). Any fruits with decay symptoms were removed and discarded during the repacking process. Fruits had been treated with the fungicide thiabendazole when originally packed but were not retreated upon repacking. Three replicate boxes each of tight-packed (tissue paper wrapped), size 100 fruits and foam tray-packed, size 70 fruits were irradiated at 0, 0.15, 0.30, 0.60, and 0.90 kGy. Treated fruit, irradiated and control were then returned to the USDA, ARS-TFRL at Wenatchee and placed in cold storage at about 1C.

Commercially packed 'Bosc' fruit were obtained from two packinghouses. Tight-packed fruit (size 120) were obtained from the Wenatchee area and pulp tray-packed fruit (size 100) from the Yakima area. The tight-packed fruits were repacked because of excessive decay several days before treatment. Tray-packed fruits had been treated with thiabendazole at harvest, stored in field bins and were packed two days before treatment. Pears from both sources were treated with thiabendazole during the packing process. Fruits were transported, irradiated, and stored as described above.

Natural disease incidence in both pear cultivars was assessed 12 weeks after treatment. Incidence of decay by all fungal pathogens was pooled for analysis. Disease incidence data from the 'Anjou' pear trial were transformed to arcsine square root values and analyzed by two-way analysis of variance. Because type of packaging and pretreatment handling of the 'Bosc' pears differed between the two sources, disease incidence data from the 'Bosc' trial were analyzed with a one-way analysis of variance with source as a block. Where significant differences among treatments were indicated, treatment means were separated with Tukey HSDT ($P \geq 0.05$).

RESULTS AND DISCUSSION

Apple Quality

Irradiation at all doses tended to reduce the firmness of all three apple cultivars used in this study (Table 1) with loss being cultivar dependent. Reduced firmness was not evident for 'Fuji' apples until irradiation exceeded 0.60 kGy. Firmness loss for 'Gala' apples occurred at doses greater than 0.30 kGy, and for 'Granny Smith' apples at doses above 0.15 kGy. Firmness of 'Granny Smith' apples was affected more than that of other cultivars by irradiation. Loss of firmness due to irradiation has been noted previously in apples (Olsen *et al.* 1989). However, firmness of all cultivars in this study would either meet or exceed the minimum acceptable level of 53.4 N established for Washington State apples (Washington Agriculture Code, 16-403-142).

Olsen *et al.* (1989) also reported a loss in TA of 'Delicious' apples as a result of irradiation. In our study, the only consistent loss in TA occurred with 'Gala' apples at dosages equal to or greater than 0.60 kGy. No loss in TA was evident for 'Granny Smith' apples and there was no consistent trend for 'Fuji'. There was likely a decline in TA for 'Fuji' apples at irradiation levels above 0.30 kGy but this response was not consistent. 'Fuji' apples receiving no irradiation were similar to the apples after exposure to 0.90 kGy. Time in storage did result in loss of TA, but this loss was not influenced by irradiation.

External color is a major consideration for grade determination of apples and can have significant influence on market return. Irradiation did not influence the external color of apples in this study (Table 2). Time in cold storage and ripening time did influence the color of all three apple cultivars, but there was no interaction between irradiation, storage or ripening time.

TABLE 1.
FIRMNESS AND TRITABLE ACIDITY OF 'FUJI', 'GALA' AND 'GRANNY SMITH' APPLES AS INFLUENCED BY IRRADIATION TREATMENT, STORAGE TIME AND RIPENING

	Firmness (N)			Titratable Acidity (% malic)		
Treatments	'Fuji'	'Gala'	'Granny Smith'	'Fuji'	'Gala'	'Granny Smith'
Radiation Dose (kGy)						
0.00	60.4a[z]	57.3a	63.7a	0.29ab	0.32a	0.57b
0.15	60.1a	57.2a	63.6a	0.30a	0.31ab	0.60a
0.30	59.9a	56.0ab	61.5b	0.29ab	0.30ab	0.59b
0.60	59.3ab	55.0b	58.7c	0.26c	0.28b	0.57b
0.90	58.0b	54.4b	55.8d	0.27bc	0.28b	0.57b
Storage (days @ 1 C)						
30	60.0a	58.0a	60.5a	0.30a	0.35a	0.60a
60	59.0b	55.8b	58.6b	0.27b	0.29b	0.54b
Ripening (days @ 20 C)						
0	62.6a	58.9a	62.6a	0.30a	0.31a	0.60a
7	58.7b	53.1b	58.7b	0.29b	0.28b	0.56b

[z]Means within treatments in a column not followed by a common letter are significantly different by Tukey's HSDT ($P \geq 0.05$).

As storage progressed from 30 to 60 days, 'Fuji' apples lost red color, indicated by increased Hunter L* and h°. 'Granny Smith' apples lost some green color, indicated by decreased hue values, but this loss was less than 1.0 unit and would likely not be noticed by the consumer (Hunter and Harold 1987). There was also some change in the color of all apple cultivars during ripening, but the changes were small and not readily apparent (<2.0 unit). Internal Hunter L* did not change as a result of irradiation (Table 2). There was a decrease in hue values for 'Gala' and 'Granny Smith' apples, indicating a darker, more yellow, interior color for apples exposed to irradiation. This change in color developed in response to 0.90 kGy for 'Gala'. A change in the interior color of 'Granny Smith' developed in response to 0.60 kGy. This change in the interior color of 'Gala' was less than 1.0 unit and would not be visible to the average consumer. The change in the interior color of 'Granny Smith' was larger (2.3 units), but would be noticable to the consumer only when comparing the interior

TABLE 2.
EXTERNAL AND INTERNAL HUNTER COLOR OF 'FUJI', 'GALA' AND 'GRANNY SMITH' APPLES AS INFLUENCED BY IRRADIATION TREATMENT, STORAGE TIME AND RIPE

	External Color						Internal Color					
	"L"			hue			"L"			hue		
Treatment	'Fuji'	'Gala'	'Granny Smith'	'Fuji'	'Gala'	'Granny Smith'	'Fuji'	'Gala'	'Granny Smith'	'Fuji'	'Gala'	'Granny Smith'
Radiation Dose (kGy)												
0.0	55.0a[z]	54.0a	64.8a	50.8a	36.9a	108.1b	71.3a	70.8ab	75.1 a	93.1	89.5 a	100.8 a
0.15	55.6a	52.7a	64.3a	53.6a	35.0a	108.4a	71.5a	71.3 a	75.8 a	93.3	89.5 a	100.2ab
0.30	56.1a	53.7a	64.3a	53.1a	35.6a	108.3ab	71.5a	70.7 b	75.4 a	93.2	89.5 a	99.8abc
0.60	54.6a	53.1a	64.5a	50.9a	34.9a	108.2 ab	71.4a	70.7 b	75.7 a	92.4	88.9ab	99.1 bc
0.90	55.8a	53.0a	54.7a	54.4a	35.2a	108.0 b	71.4a	70.6 b	75.2 a	92.8	88.5 b	98.5 c
Storage (days)												
30	55.4b	53.3a	64.8a	50.5b	36.1a	108.7 a	72.1b	78.2 a	74.1 b	89.4a	91.5 a	101.1 a
60	56.5a	53.7a	65.2a	53.9a	35.4a	108.0 b	74.7a	67.0 b	76.8 a	89.9a	87.8 b	99.2 b
Ripe (days)												
0	56.3 a	53.1a	65.2 a	52.7a	34.9 b	108.3 a	70.5 b	70.0 b	76.3 a	96.5a	89.6 a	100.0 a
7	54.6 b	53.5a	63.9 b	52.3a	36.1 a	108.1a	72.5 a	71.6 a	74.7 b	89.4b	88.8 b	99.2 b

[z]Means within treatments in a column not followed by a common letter are significantly different by Tukey's HSDT ($P<0.05$).

color of nonirradiated to irradiated apples. Time in storage and days of ripening influenced the interior color of all cultivars except 'Fiji', but all these changes would be expected and there was no interaction between irradiation, time in storage and days of ripening.

Pear Quality

Unlike apple fruit, irradiated 'Anjou' pears did not lose firmness when exposed to radiation (Table 3). In addition, 'Anjou' pears ripened normally after irradiation. However, loss of firmness was observed in unripened 'Bosc' pears (Table 3). Firmness decreased with increasing radiation dosage from 0.60 kGy to 0.90 kGy. Despite the initial loss in firmness, 'Bosc' fruit exposed to 0.90 kGy softened more slowly compared to those treated with lower dosages. Both, 'Anjou' and 'Bosc' pears ripened after exposure to irradiation, but at a slower rate. This change in the loss of firmness during ripening would likely allow one additional day of shelf-life for irradiated pears.

TABLE 3.
FIRMNESS AND TITRATABLE ACIDITY OF 'ANJOU' AND 'BOSC' PEARS AS INFLUENCED BY THE INTERACTION OF IRRADIATION AND DAYS OF RIPENING

		Firmness (N)		Titratable Acidity (% malic)	
Treatment	Day	'Anjou'	'Bosc'	'Anjou'	'Bosc'
Radiation Dose (kGys)					
0.0	0	46.9 a	55.4 a	0.27 a	0.14 a
0.15		47.7 a	55.1 a	0.26 a	0.15 a
0.30		47.7 a	54.1 a	0.26 a	0.14 a
0.60		49.5 a	51.9 b	0.26 a	0.14 a
0.90		46.8 a	49.4 c	0.26 a	0.14 a
0.0	7	10.9 b	17.3 c	0.26 a	0.12 b
0.15		11.4 b	17.7 b	0.25 a	0.13 b
0.30		11.9 b	17.4 c	0.24 a	0.13 b
0.60		12.6 b	18.4 bc	0.24 a	0.13 b
0.90		12.4 b	19.0 a	0.23 a	0.13 b

[z]Means in a column, within ripe (days) not followed by a common letter are significantly different by Tukey's HSDT ($P \geq 0.05$).

TA in 'Anjou' or 'Bosc' pears, either before or after ripening, was not affected by radiation exposure. TA in unripened and ripened 'Anjou' pears was similar, which is contrary to reported information (Drake 1994) where ripened 'Anjou' pears lost acidity during ripening. Individual carbohydrates (sucrose, glucose, fructose and sorbitol) and total carbohydrates (data not shown) also did not change as a result of radiation exposure.

Scald incidence increased with radiation dose of 0.60 kGy or greater. Three percent of control fruit exhibited scald, whereas those treated with 0.60 kGy and 0.90 kGy had 9.6% and 17.3%, respectively (Table 4). The presence of scald in 'Anjou' increased steadily as storage time progressed form 0 to 120 days and would be considered a typical response of pears in storage. Ripening also dramatically increased scald from less than 1% to 17.5% , which again would be expected. No exterior physiological problems were observed in irradiated 'Bosc' pears regardless of radiation exposure level (data not shown).

External and internal Hunter color L* and hue of 'Anjou' and 'Bosc' pears were not influenced by irradiation (Table 4). However, time in storage had a direct influence on the external and internal color of both 'Anjou' and 'Bosc'. Color changes due to storage are typical of pears where less green and more brown develop in 'Anjou' and 'Bosc' pears, respectively, with time in storage. Poststorage ripening at 20C also influenced pear external color and as ripening progressed 'Anjou' pears turned less green and more yellow, and 'Bosc' pears turned more brown.

Apple Disease Control

Decay incidence due to infection by *P. expansum* was reduced in both 'Fuji' and 'Granny Smith' at 0.60 and 0.90 kGy relative to control fruit (Table 5). Some reduction in incidence was observed at 0.30 kGy, but it was not different from that in the control fruit. No difference in decay susceptibility between cultivars was observed.

Irradiation was ineffective at reducing decay incidence due to infection by *B. cinerea* at the dosages tested (Table 6). Fewer lesions developed in wounds in 'Fuji' fruit than in 'Granny Smith' fruit indicating a difference in decay susceptibility between cultivars. This may be due to a breakdown of fruit tissues in 'Granny Smith' caused by radiation and expressed as a loss in firmness. Such tissue breakdown would likely increase the suseptibility of 'Granny Smith' fruit to decay.

There was a indication of an inverse relationship between decay incidence due to infection by *M. piriformis* and irradiation dosage in 'Fuji' fruit, but the effect was not significant (Table 6). That effect was not evident in 'Granny Smith' fruit. No difference was observed between cultivars in terms of decay susceptibility.

Pear Disease Control

Neither radiation dose nor packaging (tight versus tray-packed) affected decay incidence in 'Anjou' fruit and no interaction between factors was observed. Total decay incidence was 18.8% of which about equal proportions were caused by *P. expansum* (7.4%) and *B. cinerea* (7.9%). A relatively small amount of decay was caused by *M. piriformis* (0.4%) and other fungi (3.2%).

TABLE 4.
EXTERNAL AND INTERNAL HUNTER COLOR, AND SCALD OF 'ANJOU' AND 'BOSC' PEARS AS INFLUENCED BY IRRADIATION TREATMENT, STORAGE TIME AND RIPE

	'Anjou'					'Bosc'			
Treatment	External "L"	External hue	Internal "L"	Internal hue	Scald (%)	External "L"	External hue	Internal "L"	Internal hue
Irradiation Dose (kGy)									
0.00	65.8a[z]	97.9a	77.4a	86.7a	3.3c	63.1a	78.7a	75.3a	78.7a
0.15	65.0a	98.6a	77.6a	86.8a	7.0bc	62.7a	80.2a	75.2a	80.1a
0.30	65.1a	99.1a	77.7a	86.8a	6.7bc	62.3a	78.8a	75.2a	78.3a
0.60	64.5a	99.6a	77.7a	86.5a	9.7b	62.3a	80.2a	75.2a	80.2a
0.90	65.6a	99.1a	77.4a	86.1a	17.3a	61.8a	79.9a	75.3a	79.8a
Storage (days)									
0	62.6c	101.6a	77.2c	86.7a	0.0c	61.5cd	83.6a	75.2b	83.5a
30	63.6c	100.4a	76.4d	86.1a	6.7bc	60.9d	80.3b	74.3c	80.3b
60	65.4b	99.6b	77.6bc	86.7a	7.3bc	62.5bc	79.5bc	75.4ab	79.5bc
90	66.4b	97.0c	78.2ab	86.6a	11.0ab	63.4ab	78.4c	75.6ab	78.4c
120	68.0a	95.6c	78.5a	86.8a	19.0a	64.0a	75.8d	75.9a	75.8d
Ripe (days)									
0	63.3b	101.6a	78.4a	87.0a	0.1b	60.2b	84.3a	76.0a	84.3a
7	67.1a	96.0b	76.7b	86.1b	17.5a	64.7a	74.4b	74.5b	74.7b

[z]Means within treatments in a column not followed by a common letter are significantly different by Tukey's HSDT ($P \geq 0.05$).

Disease incidence in 'Bosc' fruit was affected by radiation dose (Table 7). The percentage of fruit decayed was reduced by about 41% at 0.90 kGy from that observed at 0 kGy (Table 7). A trend was evident in these results that shows some reduction in decay with increasing radiation dose.

Most of the decay observed on 'Bosc' fruit at each radiation dosage was caused by *P. expansum* (Table 7). However, 3.6 % of the fruit was decayed by other fungi including *Pezicula malicorticis* (H. Jacks.) Nannf., Alternaria sp., and others. Less than 1% of fruit were affected by decay caused by either *B. cinerea* or *M. piriformis* at any radiation dose.

In the experiment with inoculated apples, irradiation reduced the incidence of disease caused by *P. expansum,* but not *B. cinerea.* This differential action may explain why differences in the total amount of decay were detected in the 'Bosc' but not 'Anjou' fruit. Additionally, the slight rise in the amount of decay observed in 'Bosc' fruits treated with 0.60 kGy may be due to differential effects on the fruit and pathogen. At that dose fruit softening was shown to occur, which probably would increase susceptibility of fruit to decay, but may not have caused sufficient mortality of *P. expansum* to have affected the incidence of decay, whereas 0.90 kGy did.

TABLE 5.
EFFECT OF IRRADIATION ON INCIDENCE OF DECAY IN APPLE FRUIT (CV. 'GRANNY SMITH' AND 'FUJI') THAT WERE WOUNDED AND INOCULATED WITH *PENICILLIUM EXPANSUM*[X]

Radiation Dose (kGy)	Disease incidence (%)[Y]	
0.00	80.3	a[z]
0.15	80.6	a
0.30	59.2	ab
0.60	33.1	b
0.90	29.4	b

[X] Wounds were each inoculated with 50 μl of an aqueous spore suspension (2000 conidia/ml).
[Y] Means of 3 replicates of 5 fruit with 2 wounds/fruit
[z] Means in a column not followed by a common are significantly different by Tukey's HSDT (P≥0.05).

TABLE 6.
EFFECT OF IRRADIATION ON INCIDENCE OF DECAY IN APPLE FRUIT (CV. 'GRANNY SMITH' AND 'FUJI')THAT WERE WOUNDED AND INNOCULATED WITH *BOTRYTIS CINEREA*[W] OR *MUCOR PIRIFORMIS*

		Disease incidence (%)[x]	
Cultivar	Radiation Dose (kGy)	*B. cinerea*	*M. piriformis*
'Granny Smith'	0.0	87.2 ns[y]	35.0 ns
	0.15	96.7	41.7
	0.30	93.3	16.7
	0.60	84.5	24.4
	0.90	88.9	24.4
	Mean	90.1 a[z]	28.4 ns
'Fuji'	0.0	50.0 ns	50.0ns
	0.15	70.0	26.7
	0.30	56.7	30.0
	0.60	50.0	13.3
	0.90	76.7	6.7
	Mean	60.7 b	25.3 ns

[w] Each wounds was inoculated with an aqueous spore suspensions (50 μl) of either *B. cinerea* (1000 conidia/ml)or *M. piriformis* (500 conidia/ml).
[x] Means of 3 replicates of 5 fruit with 2 wounds/fruit.
[y] ns = no significant difference among treatments
[z] Means in a column within cultivars not followed by a common letter are significantly different by Tukey's HSDT ($P \geq 0.05$).

TABLE 7.
INCIDENCE OF DECAY IN 'BOSC' PEAR FRUIT STORED FOR 12 WEEKS AT ABOUT 1C AFTER EXPOSURE TO IRRADIATION

	Decay incidence (%)				
Dose (kGy)	*Penicillium expansum*	*Botrytis cinerea*	*Mucor piriformis*	Other fungi[y]	Total
0.0	38.8	0.9	0.9	5.3	46.0 ab[z]
0.60	53.9	0.5	0.3	2.5	57.2 a
0.90	23.4	0.6	0.0	3.0	27.1 b

[y] Especially *Pezicula malicorticis* and *Alternaria* sp.
[z] Means in a column not followed by a common letter are significantly different by Tukey's HSDT ($P \geq 0.05$).

Pear fruit used for this study were selected because they had a high probability of decaying. 'Bosc' pears in particular do not have a long storage life, especially in regular atmosphere storage. The pears in this trial were treated at the end of their usual storage life and were not assessed until the beginning of June, usually several months after commercial warehouses have sold out their stock of fruit stored in regular atmosphere. Therefore, it was not surprising to observe the high levels of decay present in fruit of either cultivar at the conclusion of this trial. The occurrence of relatively high levels of decay caused by species of fungi other than *P. expansum, B. cinerea* or *M. piriformis* can be attributed to the senescent state of the fruit at the time of assessment.

CONCLUSIONS

Low dose irradiation (<0.90 kGy) can be used as a quarantine treatment in apples and pears. Fruit response to irradiation was cultivar dependent. Some quality response was evident, but not to the extent of reducing quality grade, except for 'Anjou' pears with increased scald due to irradiation. Loss of firmness (4% to 12%) and acid content (7% to 12%) was the major response of apples to irradiation, with no change in external and only slight change in internal color for 'Gala' and 'Granny Smith'. The loss in firmness for apples, due to irradiation exposure, was not of great concern. Pears also lost firmness due to exposure to irradiation, but both 'Anjou' and 'Bosc' pears ripened normally. Ripening of irradiated 'Bosc' pears was slowed, requiring approximately one additional day to reach the same firmness levels as nonirradiated fruit. No loss of TA content was evident for pears subjected to irradiation. Scald on 'Anjou' pears was enhanced after exposure to irradiation, but only at the highest (0.90 kGy) level of irradiation. At irradiation levels sufficient to meet quarantine requirements, only very slight quality loss was evident for apples and no quality loss was evident for pears.

In this study, the potential for use of irradiation for control of decay in pome fruit was demonstrated. Decay caused by *P. expansum* was reduced at absorbed dosages of 0.60 kGy and 0.90 kGy in apples and 'Bosc' pear fruit, respectively. Apple cultivars were differentially susceptible to decay by *B. cinerea*, but not *P. expansum* or *M. piriformis* at the inoculum densities used. While some increase in shelf-life due to control of decay may be obtained at these irradiation dosages, higher absorbed doses likely will be required to achieve commercially acceptable levels of decay control. Irradiation at doses from 0.30 to 0.90 kGys has the potential as a quarantine treatment on apples and pears with little or no quality loss.

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